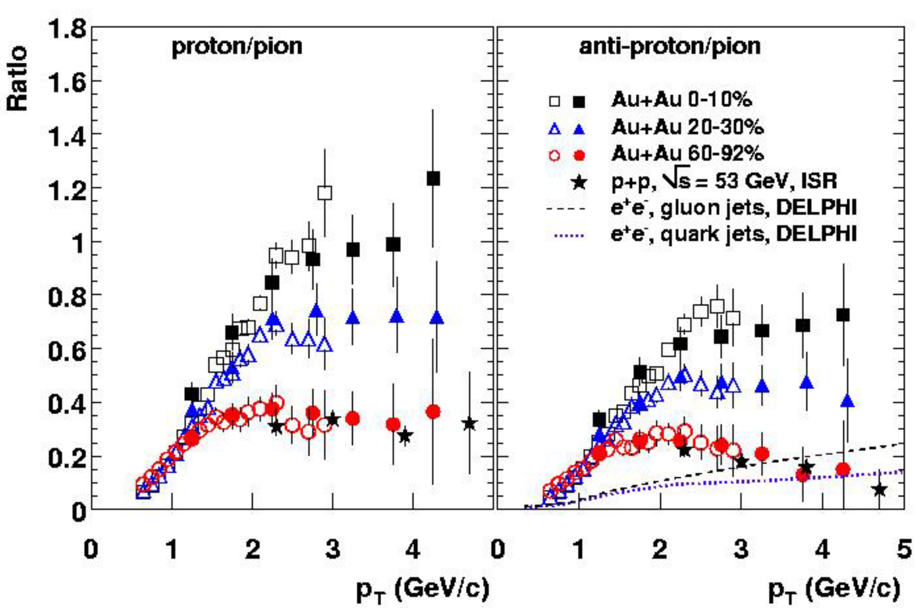
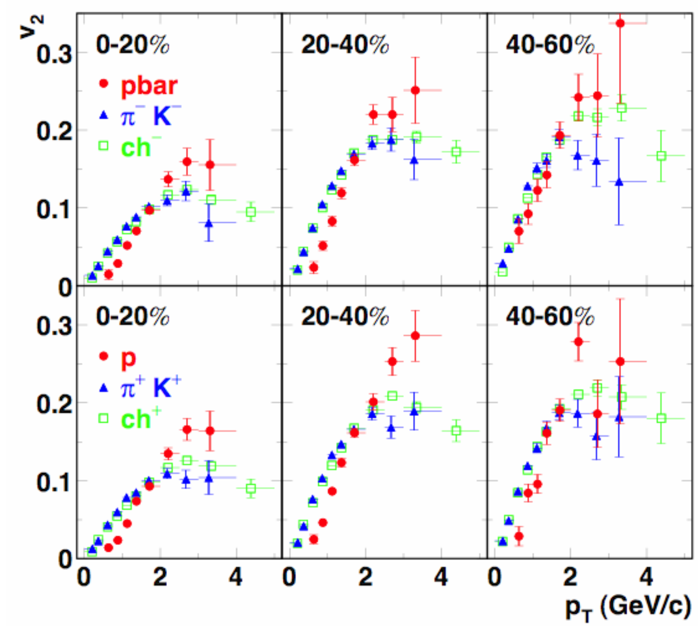
Whitepaper: Recombination

Experimental facts:

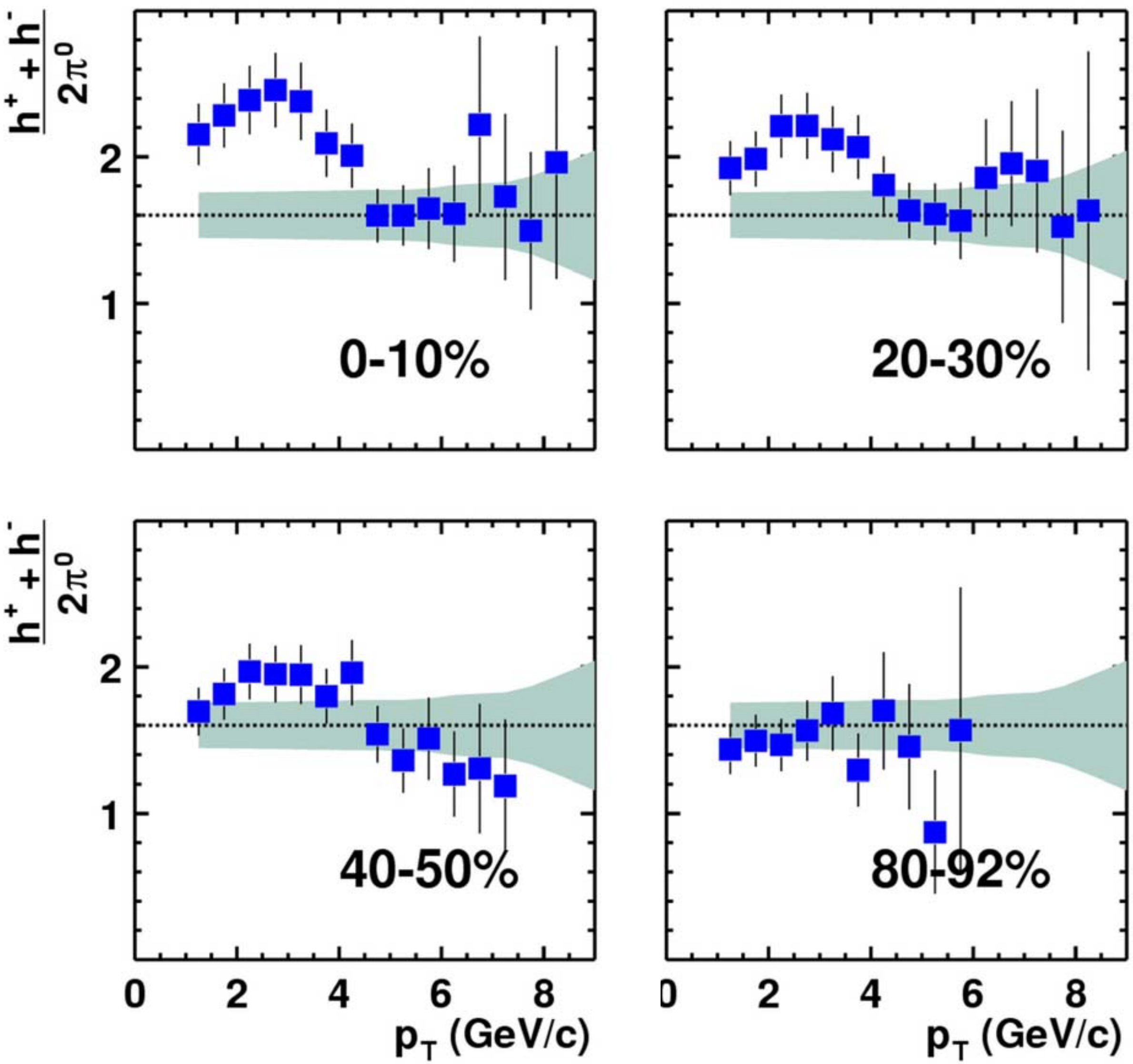
1. PHENIX observes hadron ratios at intermediate p_T that radically differ from expectations of partons fragmenting in vacuum (violation of universality expectation).

2. Azimuthal anisotropy (v2) has extremely non-trivial behaviour versus transverse momentum for various identified hadrons.





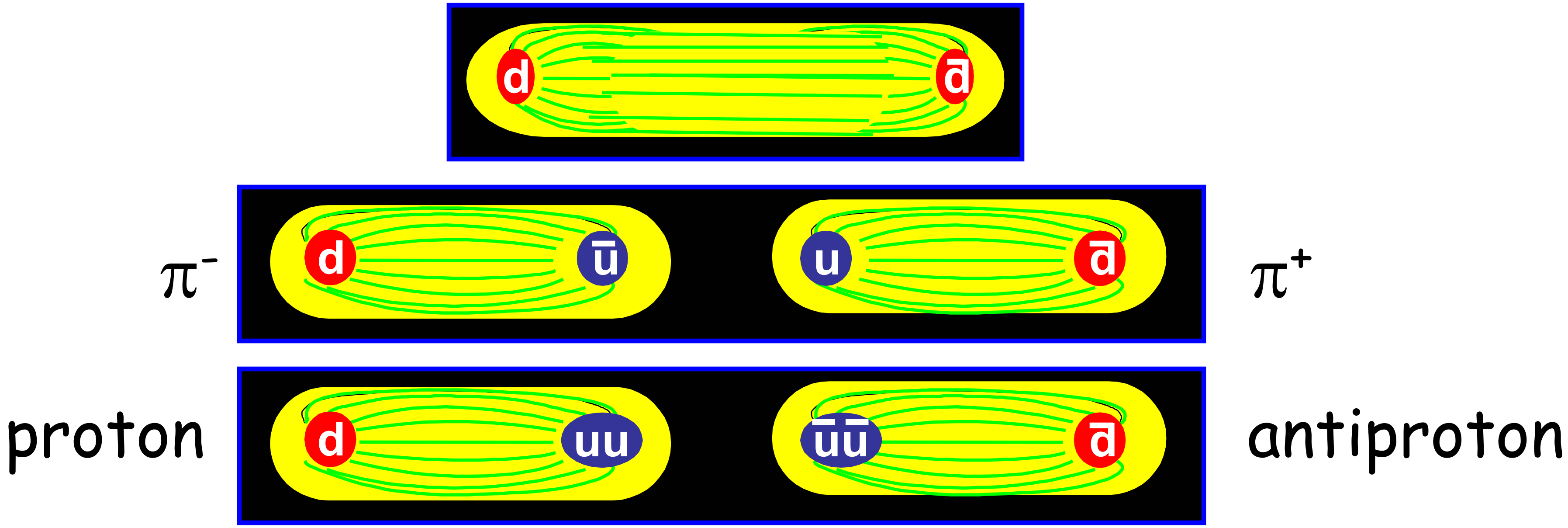
We know from h/pizero that above ~ 4-5 GeV the ratios return to vacuum fragmentation expectations.
Aerogel data for identified (anti)protons will be a key confirmation.



Simple reasoning as to why these hadron ratios are striking...

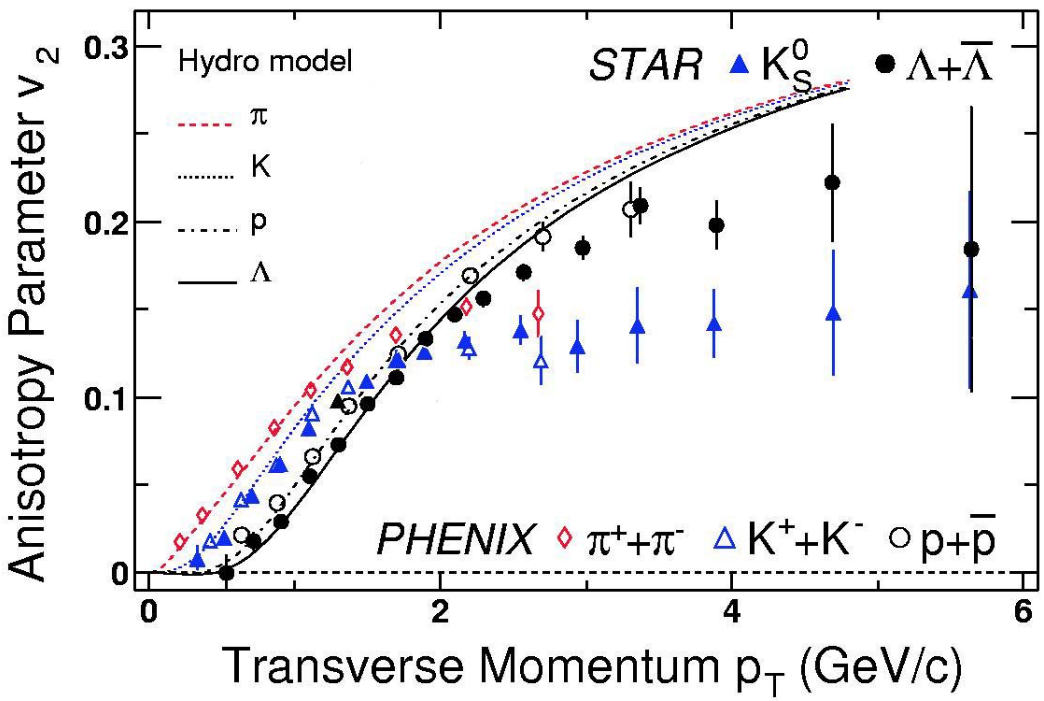
Jet fragmentation occurs when particle pairs tunnel out of the vacuum from the flux tube potential energy.
Analogous to Schwinger mechanism in QED.

Production of qqbar leading to pions is much more likely than qq qq (diquark-antidiquark) leading to protons and antiprotons.



Explanations (these are model dependent to varying degrees):

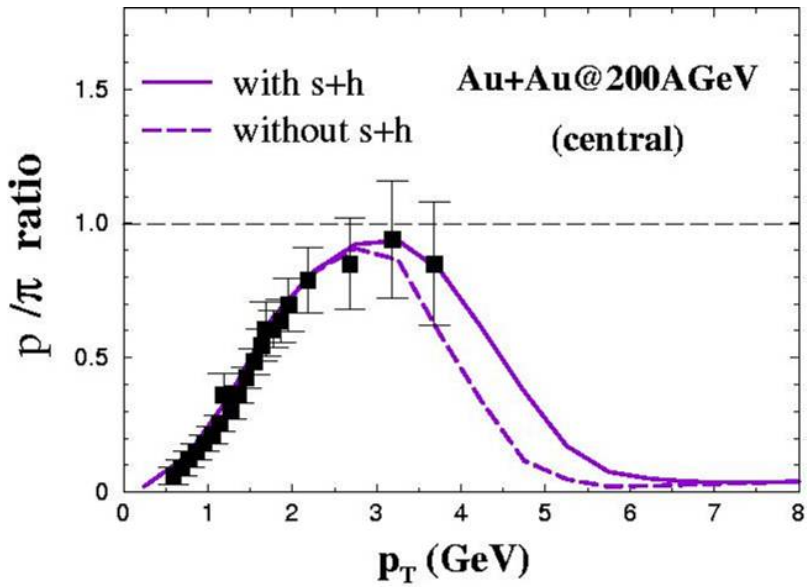
1. Excess baryons shifted from projectile and target regions (baryon junctions). Not a good explanation since very similar effect for antiproton/pion, and also anti-lambda/kaon from STAR.
1. Soft physics boosted to higher p_T by collective motion. This might explain the spectra, but cannot explain the v_2 pattern.

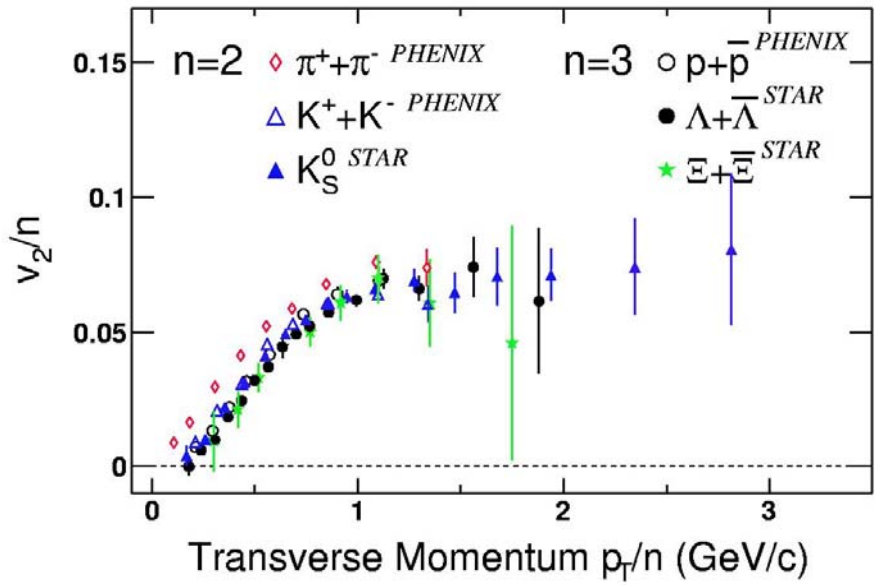


Hydrodynamic models (with one fluid) always predict v_2 becomes similar for all hadrons at high p_T.

3. Cronin effect - could possibly explain spectra (?), but not v2.

4. Recombination Models – formation of hadrons via "coalescence" of valence partons with little re-scattering afterwards.





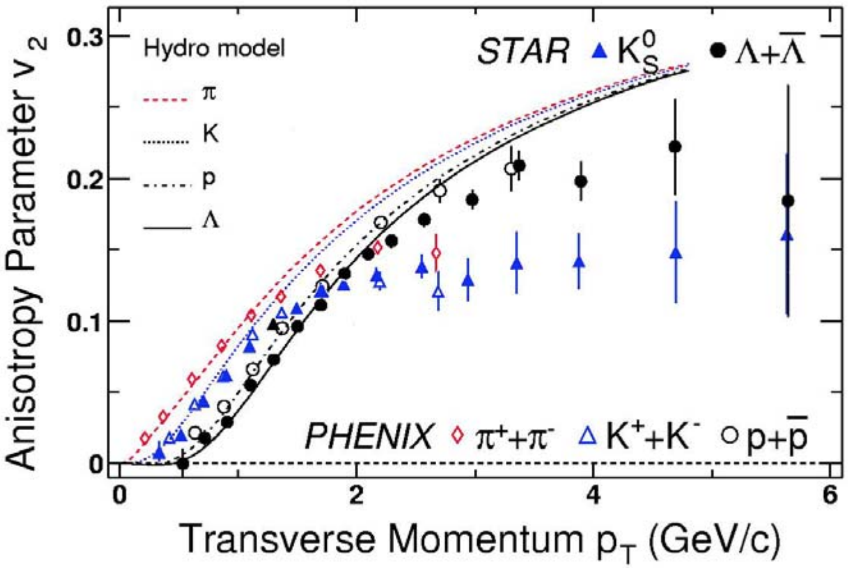
<u>If</u> hadron production is dominantly from recombination of thermal partons with thermal partons (TT), this is strong evidence for Quark-Gluon Plasma. (B. Muller)

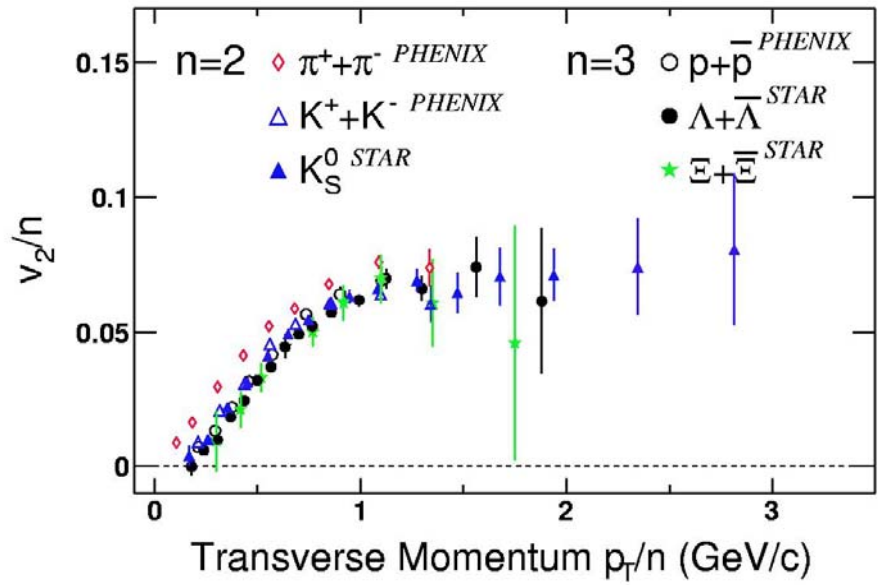
5. Other mechanisms not yet understood.

Make sure to get the facts straight...

At “low pT” (pion < 1 GeV, protons < 2 GeV), the v_2 data scales following zero viscosity hydrodynamics. It even gets the antiproton, antilambda difference!

“In the recombination model if one plots v_2/n vs p_T/n everything falls on the same line. This is empirical evidence that the quasiparticles all have the same mass.” (R.Fries)

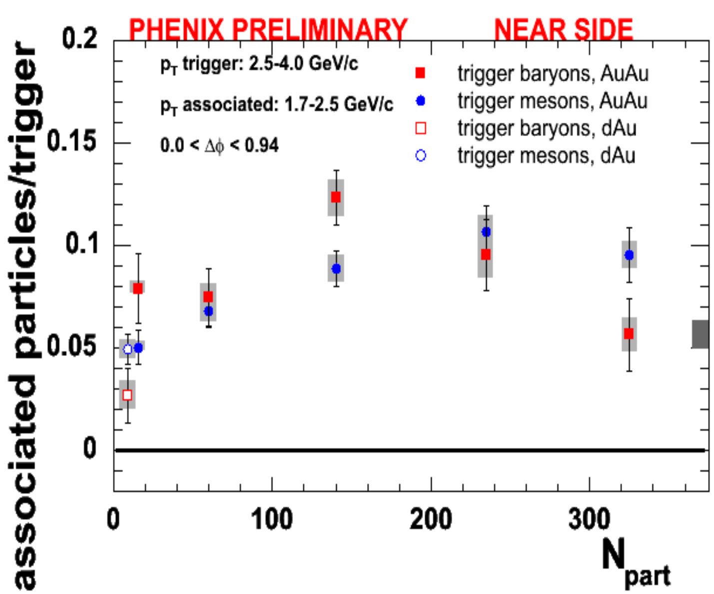


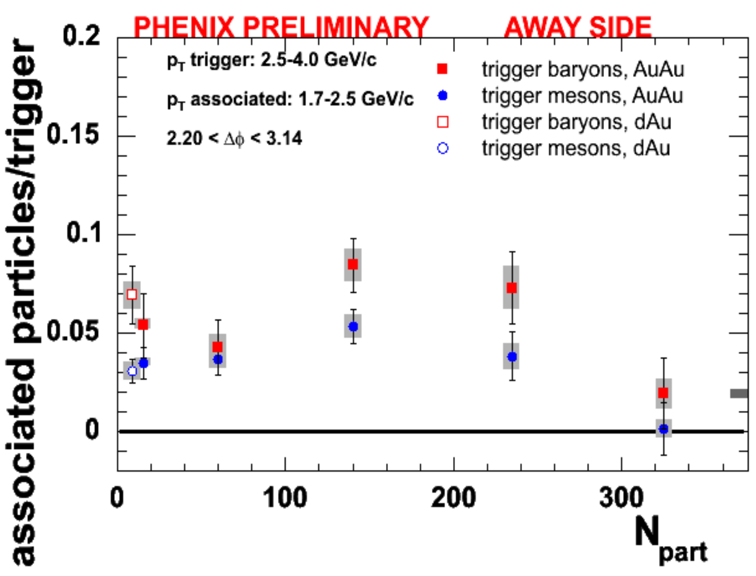


1. The pions do not fall on the “same line.”
2. If the antiprotons and antilambdas show a difference in the left plot (as described by hydrodynamics with hadron masses), how can it also fall on the “same line” in the right hand plot. Answer = it cannot.

What else can the PHENIX data address?

Look at correlations with the baryons in the p_T range 2.5-4.0 GeV.
If they are dominantly thermal-thermal recombination, there should be no angular correlation after flow removed (no jet type correlation).
Preliminary PHENIX result indicates near and away side correlation.

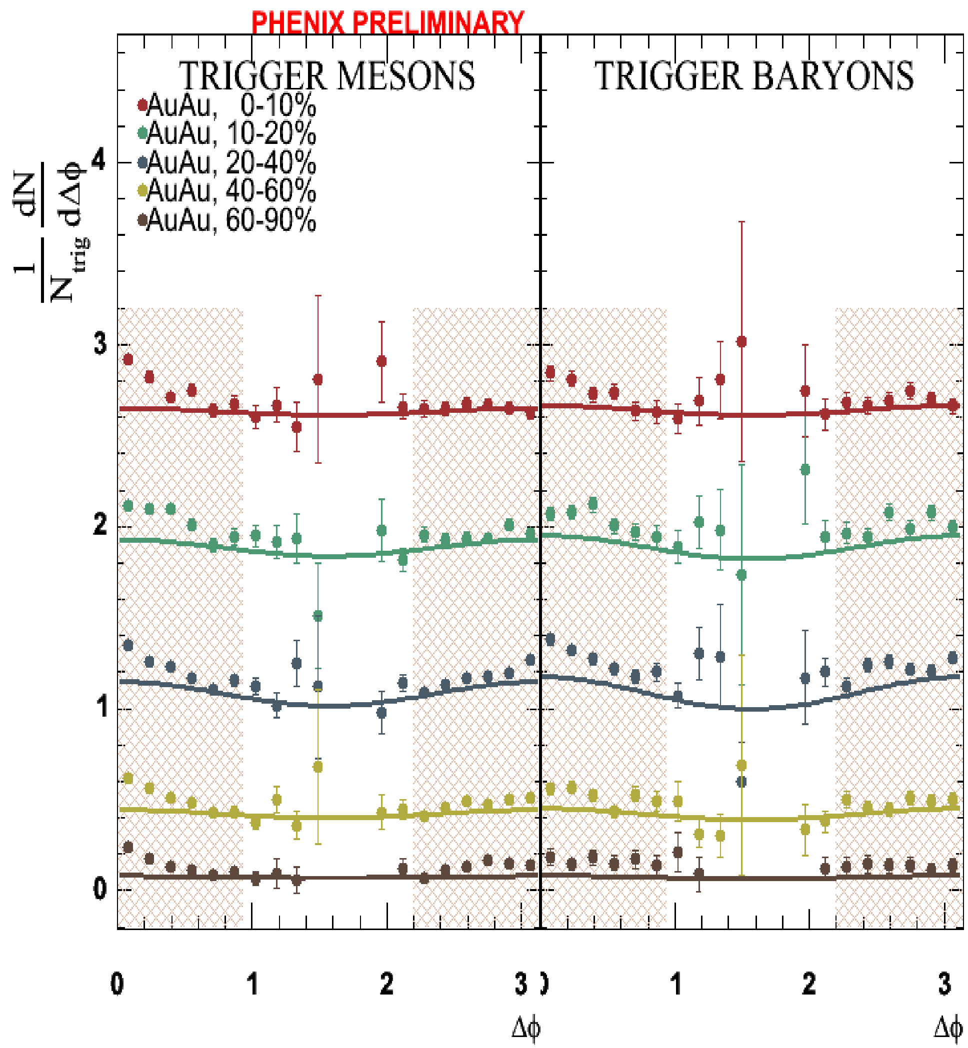




Could be one parton from jet shower recombines with one or more thermal partons.
If angular correlation required to coalesce is small compared to jet angular width, then one would expect the same correlation distribution.

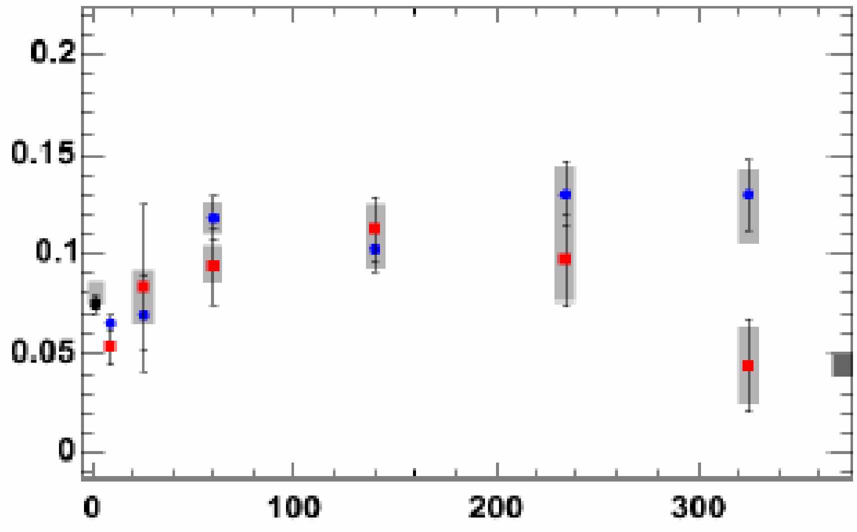
How much weight do we give this “crucial” preliminary result? This was discussed in the WPG. Progress on PPG?

- Combinatoric background level determined by convolution of trigger and associated particle rate
- v2 values taken from PRL 91 (2003) 182301 modulates combinatoric level by $1+2v_2(p_T^{trig})v_2(p_T^{assoc})\cos(2\Delta\phi)$ (solid lines in plot)



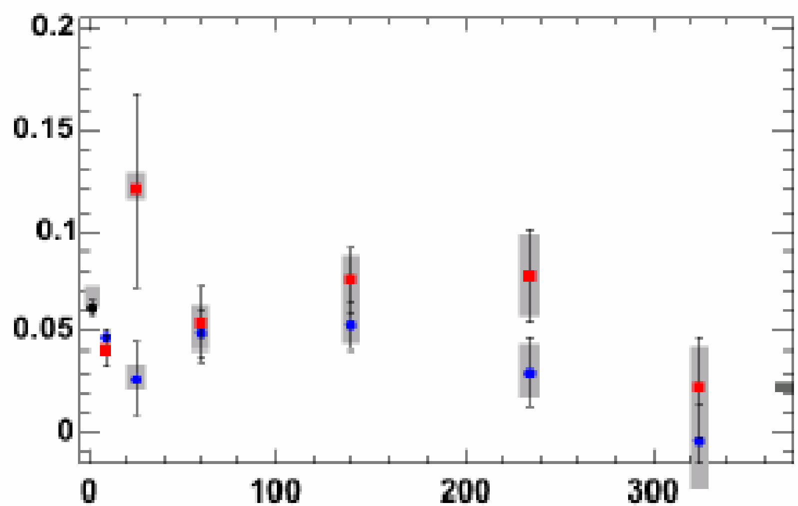
Slide from Anne Sickles QM2004

Conditional Yield: Partner 1.45->2.5GeV



Near Side

Away Side



Leading Baryons
Leading Mesons
Unidentifed Leading Particles

Latest results from Anne Sickles (presented today at hard/photon meeting)

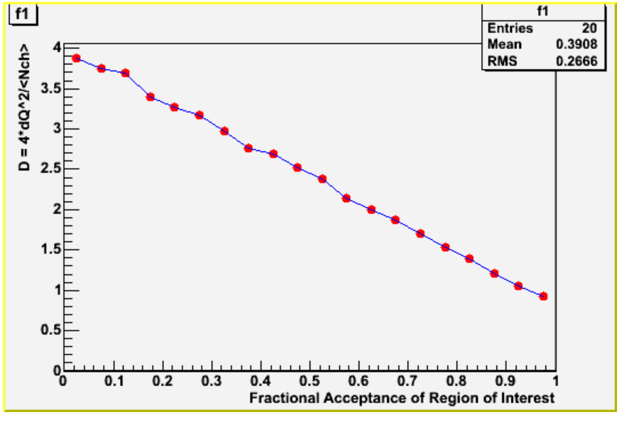
What else can the PHENIX data address?

The PHENIX charge particle ratio fluctuations paper (130 GeV AuAu) yields fluctuations that are close to the Poisson statistics limit for randomly grabbing pions out of a bag.

QGP model of Jeon, Koch predicted a factor of 4 suppression in these fluctuations.

It is often argued that if there is significant hadronic rescattering after the transition from partons to hadrons, it can increase the fluctuations back to the Poisson limit for pions. Paul Stankus has raised the issue of whether this arguement then contradicts recombination – which states that there is very little rescattering after hadrons form via coalescence.

I have shown that even if we sample only from one longitudinal slice of QGP, due to our limited acceptance, we will always get something close to the Poisson pion limit even without hadronic re-scattering.



Some things to think about... (nucl-th/0404015 for help)

Two important variants of recombination calculations...

1. High p_T using light-cone coordinates the coalescence rate is "independent of the details of the hadron wavefunction." They then apply this down to $p_T \sim 2$ GeV?
2. Use medium rest frame, traditional coalescence, but now required to "make specific assumptions about the internal wavefunction of the emitted hadrons." Entropy issue? Where are the gluon degrees of freedom?

A. Thermal-Thermal recombination – indication of QGP

B. Thermal-Shower recombination – still interesting

Use just the lowest Fock state, i.e. valence quarks (R. Fries)

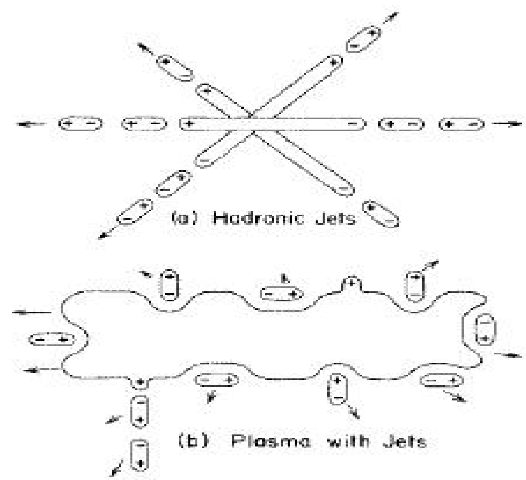
Note that I do not know of a real expansion like this for hadronic wavefunctions where the valence quarks are the lowest state.

How to reconcile the agreement of hydrodynamics with hadron masses at low pT with recombination at higher pT?

Just one thrown out idea from a phone conversation with Scott Pratt:

Imagine an intermediate p_T quark is attached to something else in the medium via a color string. Scott says that the probability to find a co-moving quark or diquark partner near in phase space is ~ 40% (must be pT dependent?). If it does not find a partner, the string stretches further and pops out another q-qbar or diquark-antidiquark pair. Then you can form a hadron via transitional fragmentation. This results is a dropping down in p_T, and you fall into the low p_T region.

Other ideas?



Some things to think about...

Does recombination take a smaller v2 value for partons, and increase it for the formed hadrons? (D. Molnar)

This is important since Molnar/Gyulassy have a parton cascade with just perturbative cross sections ("perturbative plasma" = "weakly" interacting plasma?) that underpredicts v_2 data results. Leads many to say we have "strongly interacting QGP" (sQGP).

Molnar (recent email) says that he requires artificial increase by x15 of scattering cross section to reproduce data.

However, with coalescence to boost v2 for resulting hadrons, he requires only increase by x2-3 of scattering cross section. He feels this x2-3 is possibly with 2<->3 body reactions, not in his calculation.